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Original Communication

Metatarsals in the estimation of stature in South Africans

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Abstract

To date, only one study has investigated the potential of metatarsals in the estimation of stature for forensic purposes. The morphology of these bones from clinical and paleontological perspectives is well researched in different parts of the world including South Africa. The present study aimed at assessing the usefulness of metatarsals of South Africans in the estimation of stature. For this study, 226 complete skeletons obtained from the Raymond A. Dart Collection were used in the formulation of univariate and multivariate regression equations from six linear measurements of metatarsals. The standard error of estimate for these equations was lower than that obtained for fragments of long bones and other skeletal elements studied so far for stature estimation in South Africans with the exception of intact long bones. Therefore, regression equations presented in this study can provide a reliable estimate of stature in cases where intact long bones are not available for forensic analysis.

Keywords: Stature; Metatarsals; South Africa; Forensic anthropology

1. Introduction

Recent trends in forensic anthropology have shown an increased interest in forensic age diagnosis using regression analysis.[1–4] According to Krogman and Iscan,[5] this statistical theorem was developed by Pearson in 1899 for the purpose of reconstructing stature. Intact long bones of the upper and lower extremities have been subjected to this analysis in Americans,[6,7] South Africans,[8–10] Portuguese,[11] Germans,[12] Bulgarians[13] and Turks[14] for the purpose of stature estimation. Since long bones are not recovered in their intact state in all forensic cases, researchers have also formulated regression equations from the skull,[15–17] metacarpals,[18,19] measurements of fragments of long bones,[20–24] and talus and calcaneus.[25–27] Recently, efforts have also been made at estimating stature from measurements of percutaneous bones,[28] as well as dimensions of the hands, feet and shoe prints.[29–31]

It is essential that the forensic application of foot bones such as the metatarsals, which have a good chance of being recovered, be investigated. While numerous studies have been conducted on the morphology of metatarsals from both clinical and paleoanthropological perspective, of which Zipfel[32] provided a detailed account, few researchers have investigated the usefulness of metatarsals for forensic purposes.[33,34] Byers et al.[33] made the first and only attempt to date at using the length of metatarsal bones for stature estimation. They used 130 skeletons derived from the Terry Collection at the Smithsonian Institute and Maxwell Museum of Anthropology of the University of New Mexico. Six measurements of metatarsals were used for the derivation of regression equations for estimation of stature in African and European Americans.

Since no study has been conducted on stature estimation from measurements of metatarsals in South Africans, it was the aim of this study to assess the usefulness of the length of metatarsal bones in the estimation of stature of South Africans of European descent and indigenous population groups.

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2. Materials and methods

A total of 226 complete skeletons were selected by a simple random sampling technique from the Raymond A. Dart Collection of human skeletons housed in the School of Anatomical Sciences of the University of the Witwatersrand, Johannesburg. In the selection process, consideration was given only to the two biggest groups in the collection namely the indigenous South African (ISA) and South African of European descent (SAED) population groups. While different tribes constitute the ISA population group, they were treated as a single homogeneous group because previous studies have shown that no statistically significant intertribal differences exist in the osteometric dimensions.[35,36]

The SAED population group on the other hand consists of migrants mainly from the Netherlands and other European countries.[37] It has been shown that their osteometric characteristics are different from those of Europeans and American whites.[37] The documented ages of selected skeletons ranged between 29 and 75 years. The selected skeletal materials represent 60 ISA males, 53 ISA females, 58 SAED males and 55 SAED females.

Complete skeletons with elements that constitute stature namely complete skull (with skull cap), vertebrae, femur, tibia, talus and calcaneus were used. Skeletons with missing elements such as skull caps, broken edges and those with excessive osteophytic lipping were excluded. For each selected skeleton, total skeletal height (TSH) was estimated using Fully's method[38] because previous studies by Lundy[36] and Bidmos[39] have shown that most documented cadaver lengths that form part of the catalogue of skeletons in the Raymond A. Dart Collection are not reliable.

Measurements that were taken for the calculation of TSH as described by Fully[38] and Bräuer[40] are as follows:

1. Basi-bregmatic height of the skull using a spreading caliper.
2. Maximum heights of vertebrae (C2-S1) using a sliding caliper.
3. Physiological length of the femur using an osteometric board.
4. Lateral condylomalleolar length of the tibia using an osteometric board.
5. Articulated height of the talus and calcaneus using an osteometric board.

In addition, six linear measurements of metatarsal bones were taken using a vernier caliper. Measurements of lengths of first to fourth metatarsals were taken using the same technique as described below. However, two length measurements (functional and morphological) were taken of each fifth metatarsal. All these measurements were as defined by Bräuer[40]:

(i) Lengths of metatarsals 1–4 (M1–M4): The linear distance from the apex of the capitulum to the midpoint of the articular surface of the base parallel to the longitudinal axis of the bone.
(ii) Functional length of the fifth metatarsal ($M5_F$): The linear distance between the apex of the capitulum and the dorsoplantar midpoint of the intersection between the fourth metatarsal and cuboid facets.
(iii) Morphological length of the fifth metatarsal ($M5_P$): The linear distance between the apex of the capitulum and the tip of the tuberosity.

Means and standard deviations for TSH and metatarsal measurements were obtained for each group. Regression analyses were then performed in stages after establishing that (i) data for each group followed a normal distribution pattern, (ii) variances did not show significant sex differences; and (iii) all measurements displayed high reliability. TSH was regressed on individual and various combinations of lengths of metatarsals. From these analyses, the correlation coefficient (r), standard error of estimate (SEE), regression coefficient and constant were obtained. Simple and multiple regression equations were formulated from the coefficients and constants.

3. Results

Means and standard deviations for total skeletal height (TSH) and each of the metatarsal measurements for ISA and SAED are presented in Table 1. Males consistently presented with higher mean values compared to females ($p \leqslant 0.0001$) with regard to TSH and all metatarsal measurements.

Table 2 shows regression equations that can be used in the estimation of stature from individual lengths of

Table 1
Descriptive statistics

Measurements	Males			Females			*F*-statistic	*p*-Value
	n	Mean	SD	*n*	Mean	SD		
ISA								
TSH	60	153.10	5.25	53	142.60	6.82	85.143	0.000
M1	60	63.14	3.40	53	59.89	3.78	22.587	0.000
M2	60	75.56	3.41	53	71.11	4.30	37.810	0.000
M3	60	70.51	3.65	53	68.00	4.52	10.620	0.001
M4	60	71.26	3.61	53	66.08	4.42	46.962	0.000
$M5_F$	60	61.44	3.35	53	58.53	4.14	17.029	0.000
$M5_P$	60	72.13	4.54	53	68.61	5.35	14.311	0.000
SAED								
TSH	58	157.65	6.92	55	147.11	6.13	73.153	0.000
M1	58	62.94	4.39	55	59.98	3.22	16.555	0.000
M2	58	76.41	5.04	55	72.29	4.16	22.326	0.000
M3	58	71.64	4.75	54	67.85	4.22	19.815	0.000
M4	58	70.10	4.64	54	65.90	4.16	25.304	0.000
$M5_F$	58	62.30	4.73	55	59.05	3.92	15.723	0.000
$M5_P$	58	73.05	5.02	55	68.50	5.27	22.094	0.000

ISA: Indigenous South Africans; SAED: South Africans of European descent; TSH: total skeletal height; M1–M4: length of metatarsals 1–4; $M5_F$: functional length of fifth metatarsal; $M5_P$: physiological length of fifth metatarsal.

Table 2
Equations for stature estimation (in cm), correlation and standard error of estimate using individual measurements

Equations		Correlation	SEE
ISA male			
1	$0.96M1 + 92.67$	0.62	4.16
2	$0.96M2 + 80.62$	0.62	4.14
3	$0.87M3 + 91.75$	0.60	4.22
4	$0.64M4 + 107.42$	0.44	4.76
5	$0.83M5_F + 102.31$	0.53	4.50
6	$0.68M5_P + 103.92$	0.59	4.28
ISA female			
1	$1.30M1 + 64.97$	0.72	4.79
2	$1.13M2 + 61.99$	0.72	4.81
3	$1.05M3 + 71.04$	0.70	4.94
4	$1.03M4 + 74.50$	0.67	5.12
5	$1.03M5_F + 82.43$	0.62	5.38
6	$0.69M5_P + 95.39$	0.54	5.80
SAED male			
1	$0.91M1 + 100.49$	0.58	5.71
2	$0.96M2 + 84.00$	0.70	4.97
3	$0.98M3 + 87.41$	0.67	5.16
4	$0.98M4 + 88.65$	0.66	5.24
5	$0.96M5_F + 97.73$	0.66	5.26
6	$0.83M5_P + 97.19$	0.61	5.54
SAED female			
1	$1.39M1 + 63.57$	0.73	4.22
2	$1.07M2 + 69.98$	0.72	4.28
3	$1.01M3 + 78.78$	0.69	4.54
4	$1.00M4 + 81.00$	0.68	4.56
5	$0.97M5_F + 89.89$	0.62	4.86
6	$0.74M5_P + 96.61$	0.63	4.79

metatarsals for each biological group. In the ISA group, moderate positive correlation was obtained between all measurements and TSH in the male sample (0.44–0.62) while females presented with moderate to high correlations (0.54–0.72) (Table 2). In the SAED group, the range of correlation obtained for males (0.58–0.70) was similar to that obtained for females (0.62–0.73). M2 to M4 consistently showed high correlation in all groups except for the male ISA sample. The lowest correlation (0.44) was obtained in this group for M4 while the highest correlation of 0.73 was shown by M1 in the SAED female sample (Table 2).

The lowest standard error of estimate was obtained for the equation that utilized M2 in the ISA male group (4.14) while that for physiological length of M5 in the ISA female group (5.80) presented with the highest value of SEE (Table 2). The standard error of estimate for these equations ranged between 4.14 for ISA males (function 2) and 5.80 for ISA females (function 6). In estimating stature from equations presented in Table 2, it is advised that equations with high correlation coefficients and low standard errors of estimate should be used for each biological group. Regression equations presented for M2 in all groups consistently fit this profile.

Presented in Table 3 are the best multivariate equations with reasonable application. A higher range of correlation coefficient (0.67–0.76) and lower standard error of estimate (3.81–5.07) were obtained which indicates a higher degree of accuracy of regression equations derived from combination of measurements.

Table 3
Equations for stature estimation (in cm), correlation and standard error of estimate using combination of measurements

Equations		Correlation	SEE
ISA male			
1	$0.64M1 + 0.39M5_P + 85.07$	0.67	3.96
2	$0.58M1 + 0.99M2 - 0.52M4 + 79.44$	0.69	3.92
3	$0.54M1 + 0.75M2 - 0.61M4 + 0.35M5_P + 81.15$	0.71	3.81
4	$0.53M1 + 0.68M2 + 0.21M3 - 0.54M4 - 0.33M5_F + 0.43M5_P + 81.66$	0.72	3.85
ISA female			
1	$0.81M1 + 0.53M3 + 58.21$	0.75	4.58
2	$0.81M1 + 0.70M3 - 0.17M5_P + 58.46$	0.76	4.60
3	$0.71M1 + 0.34M2 + 0.49M3 - 0.20M5_P + 56.54$	0.76	4.62
SAED male			
1	$0.71M2 + 0.31M5_F + 83.69$	0.71	4.96
2	$0.58M2 + 0.31M5_F + 0.17M5_P + 81.90$	0.71	4.98
3	$0.78M2 - 0.50M4 + 0.47M5_F + 0.28M5_P + 82.61$	0.72	4.98
4	$0.02M1 + 0.87M2 - 0.29M3 - 0.35M4 + 0.49M5_F + 0.30M5_P + 82.27$	0.72	5.07
SAED female			
1	$0.81M1 + 0.53M2 + 60.32$	0.75	4.10
2	$0.84M1 + 0.65M2 - 0.16M5_F + 59.92$	0.76	4.12
3	$0.85M1 + 0.59M2 - 0.38M5_F + 0.22M5_P + 61.92$	0.76	4.14

4. Discussion

Trotter and Gleser[6,7] conducted arguably the biggest studies on stature reconstruction. They[6,7] concluded that since regression equations are population and sex-specific, anthropologists should limit the use of such equations to the population and sex groups from which the equations were derived. Many other studies are in agreement with this observation.[8–11,18–20,25,26] Contrary to the widely accepted recommendation of Trotter and Gleser,[6,7] Byers et al.[33] presented equations for combined data for male, female and all samples in addition to those derived for each biological group. They[33] combined data for Afro-American ($n = 9$) and Euro-American ($n = 57$) males to derive a common equation for males. A similar procedure was carried out for Afro-American ($n = 7$) and Euro-American ($n = 49$) females. Finally, they[33] combined data for the four biological groups in an attempt to derive a single equation for stature estimation for Americans of both population groups and sexes.

This effort can be justified in a situation where only metatarsal bones are available for forensic analysis. Since this is a very unlikely situation, the reason for deriving such equations is unknown. Since the distribution of sample size in the study[33] has a greater preponderance of Euro-American individuals, it will therefore render the combined equation biased towards that population group. It can be inferred that if there is a statistically significant difference between mean measurements for the two population groups for each sex, the equations will significantly

overestimate or underestimate stature of the Afro-American group. Since the authors[33] failed to present descriptive statistics for samples used, no comparison could be made between the biological groups they studied and samples used in the present study. A comparison of mean measurements of metatarsal lengths in the current study (Table 1) showed statistically significant sex differences for each population group. This is in support of observations made from previous studies on foot bones[25,26] thereby confirming sexual dimorphism of metatarsals.

Byers et al.[33] reported moderate to strong relationships between metatarsal lengths and stature with correlation coefficients that ranged between 0.59 and 0.89. Most of these coefficients were greater than 0.60. A similar result was obtained in the present study. All metatarsal lengths showed a moderate to strong correlation with TSH except M4 (ISA male) and $M5_P$ (ISA male and female) that presented with coefficient of less than 0.6. The accuracy of regression equations from the Byers et al.[33] study and the present study are also worth comparing.

The accuracy of a regression equation in the estimation of stature depends on the value of its standard error of estimate (SEE). This is defined as a measure of the expected accuracy of a regression equation in the estimation of the stature of an individual from the same population group from which the equation was originally derived. A high value for SEE suggests a low accuracy and vice versa. The range of SEE for regression equations for estimation of stature using individual metatarsal lengths in ISA males was similar to that obtained for SAED females (Table 2). These equations presented with lower SEEs compared with those obtained for ISA females and SAED males (Table 2). The range of SEEs from multivariate equations (3.81–5.07) was slightly lower than that obtained for univariate equations (Table 3). Therefore, regression equations derived from combinations of measurements will present better accuracy compared to those formulated from single variables.

In the Byers et al.'s[26] study, the best accuracy was obtained for regression equations that utilised M3 for the African American female group (3.99) while the lowest accuracy was obtained for the regression equation using M5 (functional) for the combined data group (7.6). This range is higher than that obtained in the present study (3.81–5.07) which indicates a better predictive accuracy of equations derived in this study. Also, the SEEs obtained from previous studies in South Africa for the calcaneus (4.0–6.3), fragments of tibia (5.2–6.7) and skulls (4.4–6.2) were higher than those found in the present study (3.7–5.3). However, regression equations derived for intact long bones (SEE for ISA = 1.8–5.3, SEE for SAED = 1.8–5.5) will provide a more accurate estimate of stature compared with those formulated in this study.

5. Conclusion

Lengths of metatarsals showed moderate to high correlation with total skeletal height which indicates a good association between predictor and dependent variables. Standard error of estimate for derived regression equations is lower than those obtained for the skull, fragments of tibia and the calcaneus which shows that metatarsals have a better predictive efficacy in stature estimation compared to these skeletal elements. Since SEE of regression equations derived for intact long bones is lower than that presented in the present study, it is recommended that stature should be estimated from these bones when they are available for forensic analysis. In their absence, regression equations presented in this study can provide a reliable estimate of stature.

Conflict of Interest

None declared.

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